Snowfall Observations at NASA Wallops Island Flight Facility

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Introduction

The National Aeronautics and Space Administration (NASA) Global Precipitation Measurement (GPM) ground validation program conducted a field study of precipitation observations at the NASA Wallops Flight Facility (WFF) during 2013-14 winter season. A key motivation of this study is to investigate the microphysical characteristics of falling snow for the GPM algorithm developers. Specifically, the algorithm developers have a great interest in parametric form of snowfall velocity, snow size distribution (SSD) including maximum diameter, and snow density. This study utilizes collocated measurements of three different optical disdrometers and weighing bucket gauges to address the three major characteristics of falling snow aforementioned above. This is an arduous task as individual flakes have complex shape and composition in contrast to liquid and spherical/oblate raindrops.

Disdrometer/Gauge Data Acquisition Network

The WFF network comprises of six sites, which encompass six automated Parsivel[2] units (APU), six two-dimensional video disdrometers (2DVD), and a precipitation imaging probe (PIP). All units measure the size and fall velocity of hydrometeors. PIP and 2DVD provide information on the shape of individual particles. The network also hosts Automated Surface Observing System (ASOS) complete weather station site, which includes one of the two Pluvio200 weighing bucket gauges, which measure the melted equivalent snow accumulation. The second Pluvio200 and one of the three disdrometers are collocated at the PAD site. The largest distance between sites is 2.3 kilometers (between the Water Treatment Plant, WTP and the Visitor's Center, VC) while the shortest distance is 0.5 kilometer between the PAD and ASOS sites respectively. Pictures of the instrumentation at WFF are shown above.

It is important to note that the disdrometers calculate different diameters of the frozen precipitation. PIP calculates the circular equivalent-area diameter, 2DVD calculates the equivalent-volume spherical diameter and APU calculates the volume-equivalent diameter.

ANNUAL STATISTICS	2013-2014 STATISTICS	TOTAL SNOWFALL ACCUMULATION IN PAST YEARS
ANNUAL SNOWFALL = 7.9'' (200.66mm)	SNOWFALL = 13.1'' (332.74mm)	2012-2013 – 8.4'' (213.36mm)
ANNUAL NUMBER OF SNOWY DAYS = 5	NUMBER OF SNOWY DAYS = 12	2011-2012 – 0.5'' (12.7mm)
ANNUAL TOTAL PRECIPITATION = 39.2'' (995.68mm)		2010-2011 – 17'' (431.8mm)
ANNUAL PRECIPITATION DAYS = 117		2009-2010 – 14.1'' (358.14mm)

Precipitation Climatology

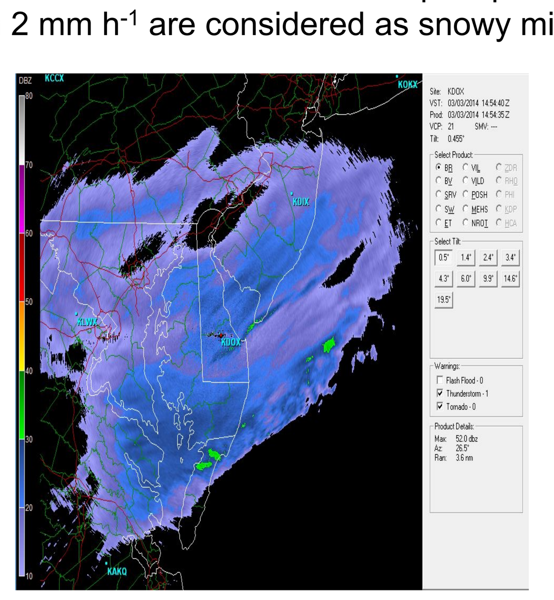
WFF recorded more snowy days and accumulation with respect to the long-term climatology. Most of the snowfall fell during January and March 2014. The late March snow event (March 25th) was an anomaly for the region.

Sources: National Weather Service, National Climatic Data Center

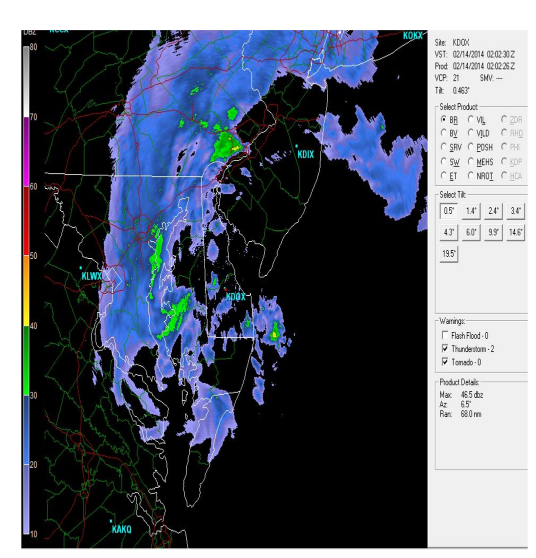
Snow Events (UTC)

There were 8 snow events during winter of 2013-14. Snowy minutes were reported through an ASOS present weather sensor. An alternative algorithm using PIP precipitation rate was also used. PIP calculates the precipitation rate based on measured size distribution and fall velocity. In the presence of snow, precipitation rate calculated from terminal fall speed of rainfall is erroneous and is much higher than the rate calculated based on the measured fall speed. The ratio and difference between the two precipitation rates are used to identify the snowy minutes. The ratio less than 0.25 and the difference more than 2 mm h^{-1} are considered as snowy minutes.

EVENT (#)	DURATION	Average Temperature
1	JAN03 06:00 – JAN03 11:30	-1.441°C
2	JAN21 22:05 – JAN22 10:03	-5.413°C
3	JAN28 20:41 – JAN29 12:40	-9.562°C
4	FEB14 01:58 – FEB14 05:12	1.952°C
5	FEB15 20:41 – FEB15 23:23	2.202°C
6	MAR03 14:40 – MAR03 22:00	-4.465°C
7	MAR17 08:04 – MAR17 20:53	0.824°C
8	MAR25 18:50 – MAR26 06:13	1.045°C

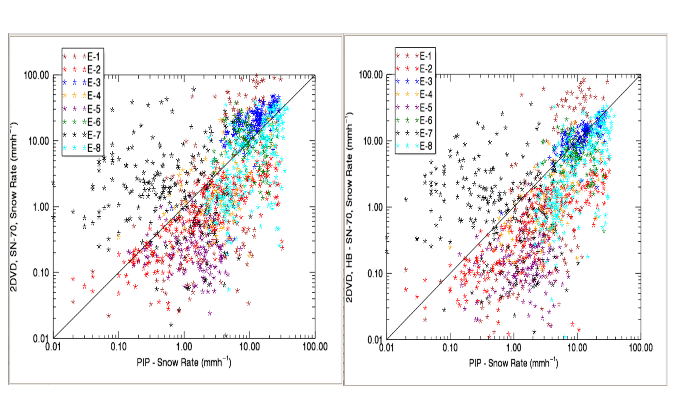


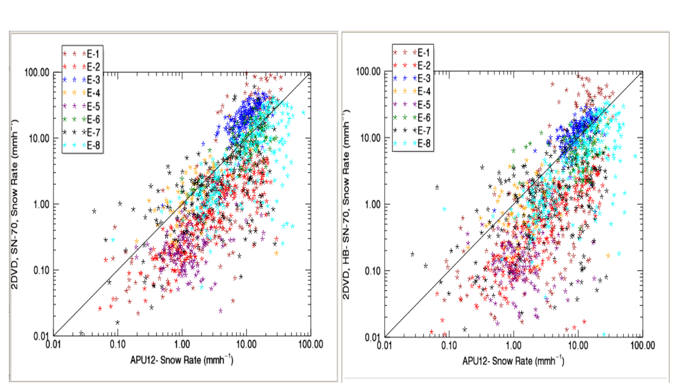
February 14 Snow Event, 02:02 UTC

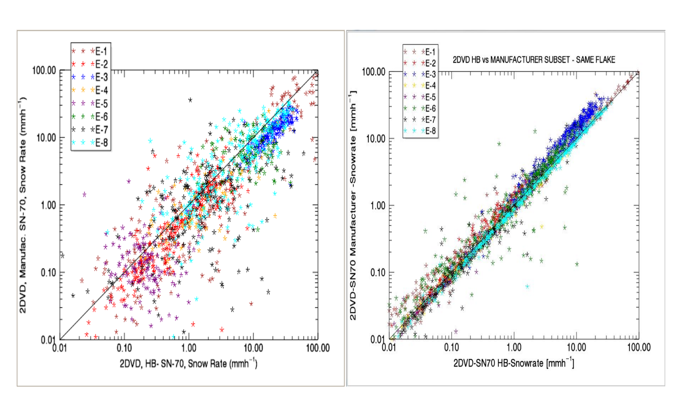


March 03 Snow Event, 14:54 UTC

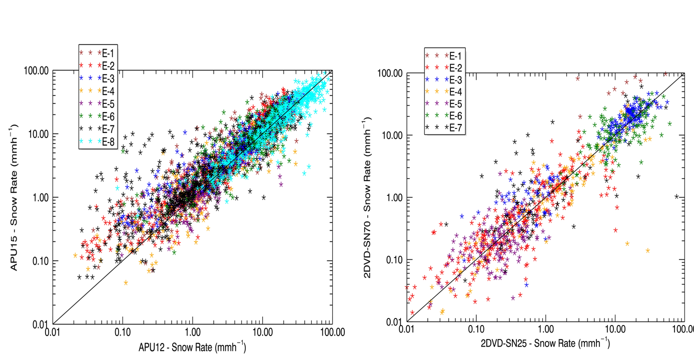
Snow Rate





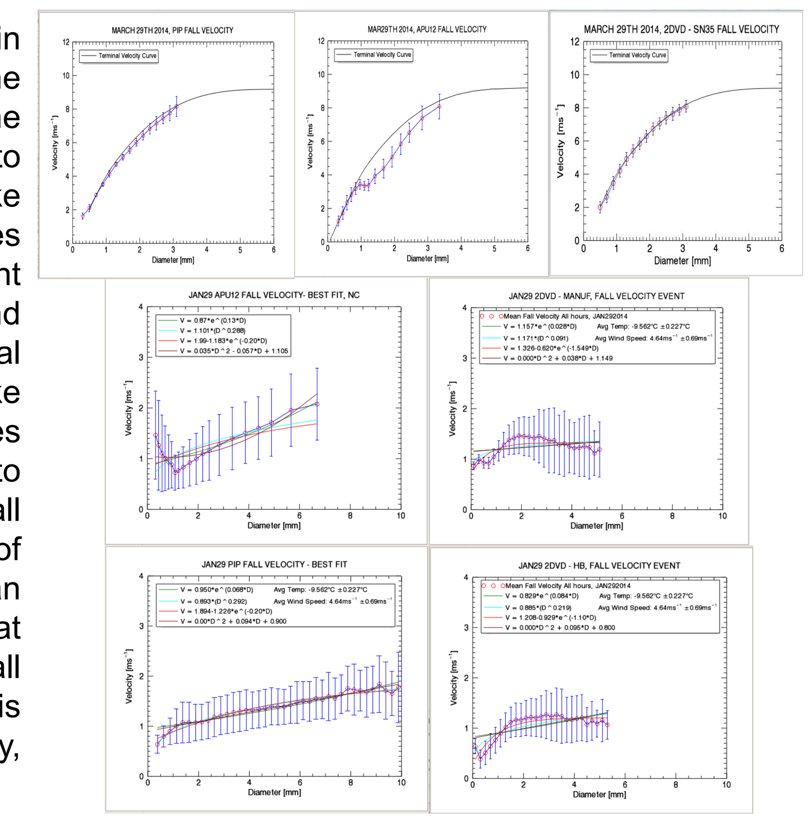


The snow rate, which is a function of flake size and counts, was compared to evaluate the performance of the disdrometers. For PIP, the snow rate is also a function of fall velocity. Considering eight snow events (labelled E1-E8 in chronological order), there were only a few events (e.g. E8), where one disdrometer had both under- and over-estimation with respect to another disdrometer. The scatter was more spread in number of events (e.g. E5, E7) indicative of poor agreement, while a few events had relatively better agreement (e.g. E3, E8). Consequently, on the bottom far right, the same type of disdrometers at 0.5 km apart had a better agreement than the collocated different types of disdrometers. This shows the importance of the definition of flake size. There were also considerable differences in snow rate between the two different 2DVD algorithms where a particle in the A plane is typically matched with a different particle in the B plane (top far right). However, when a subset was taken into an account; where both algorithms detected the same flake in A plan, the snow rates between the two are in good agreement.



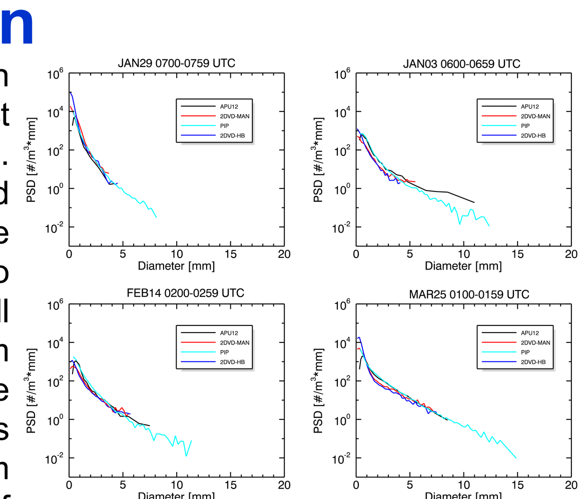
Snow Fall Velocity

The parametric of snowfall velocity is a fundamental quantity in precipitation retrieval algorithms and is required to calculate the snowfall rate from size distribution. The fall velocity depends on the mass, shape and the orientation of the flake and is expected to increase with size rather gradually than raindrops. A typical snowflake falls at a rate of 1 m s^{-1} capping at 4 m s^{-1}. In this study, fall velocities of the flakes from APU, PIP, and 2DVD were analyzed on an event and hourly basis. Furthermore, the two 2DVD algorithms, HB and Manufacturer were analyzed since they utilize two different individual snowflake matching algorithms. Mean and standard deviation of flake fall velocities were calculated for a size range when 20 or more flakes available in that bin. Four different empirical fits were then applied to the observed mean fall velocities. To evaluate the accuracy of fall velocity measurement, it is important to test the performance of disdrometer in rain where a well-established terminal fall velocity can be used as a reference. Fall velocities of March 29th event show that 2DVD and PIP performed fairly well, while APU underestimates the fall velocity approximately 1 m s^{-1} at 1mm in diameter. Similarly this software error is reflected in the January 29th snow event. Additionally, the temperature and wind speeds of the event are also shown.

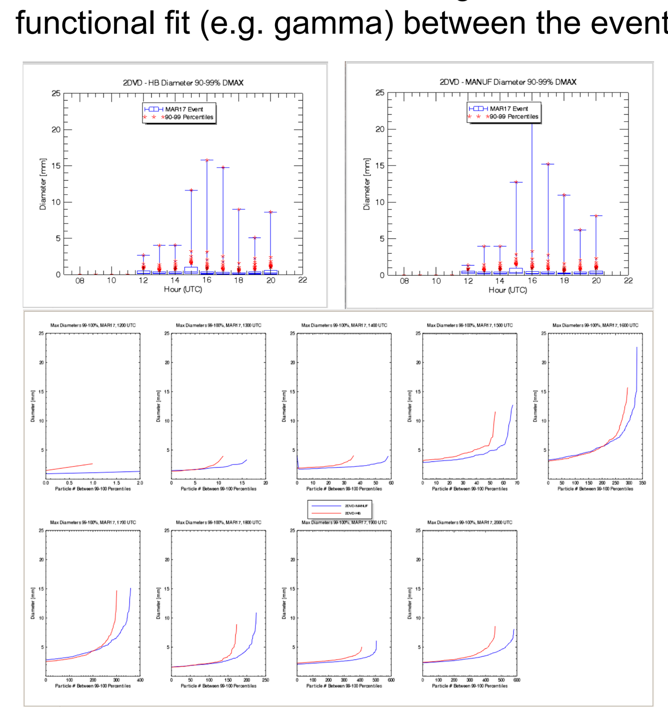


Snow Size Distribution

The parametric form of SSD is an additional fundamental quantity in precipitation retrieval algorithms. The radar observables and snow parameters are integral product of SSD. The SSD is a function of size and counts of flakes in a sampling volume. When it is calculated from 2DVD or APU, the snowflake fall velocity is also required across the sampling cross section. In this analysis, the hourly and event composite size distributions from APU, PIP, and two different version of 2DVD were compared to each other. Despite the differences in measurement principles of the size and fall velocity between the disdrometers, a good agreement was evident between 1-4 mm diameter. PIP was able to capture very large flakes (5-15 mm). An order of magnitude difference in the concentration of small flakes(<1mm) between the events was evident. Additionally, the slope and width of the SSD had significant differences from one event to another, revealing that there are significant differences in parameters of functional fit (e.g. gamma) between the events.

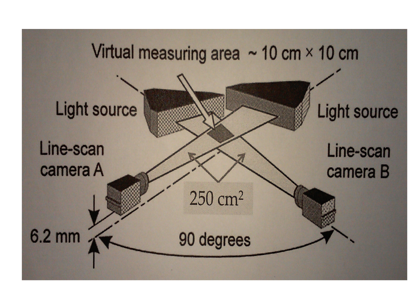


Maximum Diameter

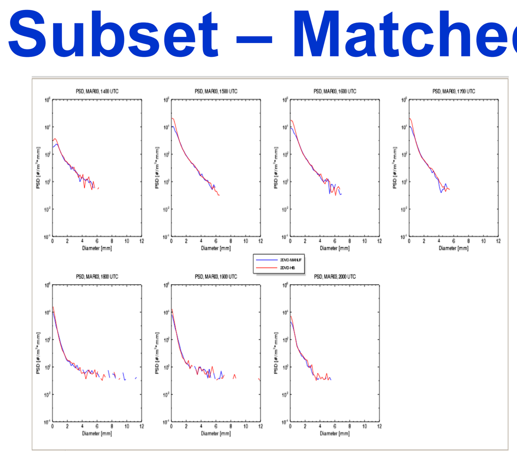


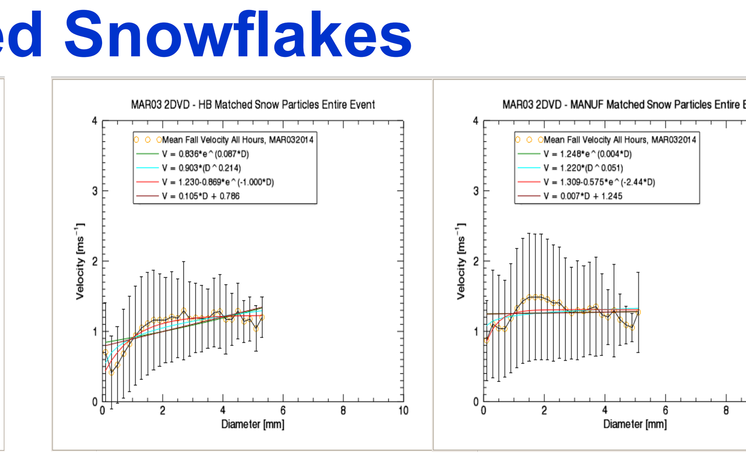
The maximum diameter (Dmax) is one of the required parameters in modeling snowflake size distribution. However, it is highly variable from a few millimeters in the presence columnar flakes to a few centimeters in the presence of dendritic flakes. By definition, it is the largest flake in a sample of air. For optical disdrometers the sampling volume is orders of magnitude smaller than weather radars, it is simply a catch or miss. The time integration may not be the solution since flakes have a stochastic nature with time. The differences in definition of flake size (horizontal dimension verses equivalent diameter) is another factor in disdrometer derived Dmax. In this study, the percentiles of Dmax were analyzed between the 90-99% based on hourly observations with 1% increment. Gradual increases in Dmax were observed between the 90-99% and most of the 99-100% but a sharp increase in size was evident in the presence of a few very large flakes. This segment of the study was implemented for the HB and manufacturer algorithms of 2DVD shown for the March 17th event. This study will be extended to PIP observations.

Subset – Matched Snowflakes



Kruger and Krajewski [2002]

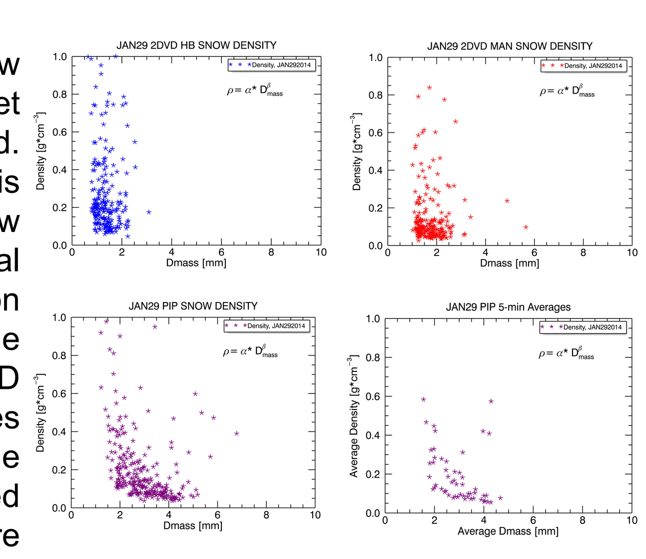




The re-matching of HB algorithm results in differences in both size and fall velocity of falling flakes. The HB algorithm results in lower flake concentrations than the manufacturer, however HB offered a multiplication factor for the subsample. In this study, a subset of 2DVD observations were constructed through matching the time stamp of both algorithms. This matched subsample results in the same number of flakes at a given minute while the size and fall velocity are still different for each flake. The HB algorithm had more small flakes as shown in March 3rd event. Mean and fall velocities had a more defined increase with size in the HB than in the manufacturer algorithm at sizes less than 2 mm diameter. This resulted in differences in derived fall velocity relationships.

Snow Density

The snow density is a required quantity to calculate the water equivalent of snow and reflectivity from SSD. It has a wide range from near 1 g cm^{-3} at very wet snow to 0.01 g cm^{-3} at very dry snow. However it is not directly measured. Rather, it is determined either as the bulk density or function of flake size. In this study, the snow density is determined by utilizing the ratio of the melted snow rate over the observed snow rate produced from Pluvio200 gauge and the optical disdrometers, respectively. A wide range of snow densities were evident on Jan29th event although this was a well-defined cold and dry snow event. The mass weighted flake diameter, Dmass, was mostly between 1.5-2.0 mm in 2DVD in the presence of abundant small flakes. In contrast, PIP recorded bigger flakes resulting in relatively higher Dmass. The relatively sparse high density regime (>0.4 g cm^{-3}) was probably due to noise since the observations were integrated at 1-minute. To smooth the 1 min observations, 5 minute averages were considered, expressing the ideal density regime for the event.



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References

Hoschen,H., 2013: Falling Snow Characteristics and its Variability. Master Thesis.Meteorological Institute, The University of Bonn.

Rustmeier, E., 2008: Snow Measurements with Disdrometers. Diploma Thesis. Meteorological Institute, The University of Bonn.

Huang, G.J., V.N. Bringi, D. Moisseev, W.A. Petersen, L.Bliven, and D. Hudak, 2015: Use of 2D-video disdrometer to derive mean density-size and Ze-SR relations: Four snow cases from the light precipitation validation experiment. *Atmospheric Research*, 153, 34-48.

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